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Supplementary Information

Life-cycle based Dynamic Assessment of Mineral Wool Insulation in a Danish Residential Building Application

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Section 1: Detailed Methodology

1.1 Danish reference house

Although it can be useful for scenario testing, the selection of a specific building for the purpose of a generalized analysis poses several significant obstacles. Factors such as the proportion of glazing to wall area, the total size of the home, and many others may have an impact on the effectiveness of insulation (Sadineni, Madala, and Boehm 2011). Such variation would also affect the insulation's apparent environmental impact. This indicates that the modelled building must be representative of the market segment being analyzed. For the purposes of this study, average values for building element performance based on Danish residential construction are used to reduce such bias.

Overall, the average single family home in Denmark has 144 m^2 of heated area (Kragh and Rose 2011). On the other hand, between 1998 and 2009, the average single family home built in Denmark had 163 m^2 of heated floor area and a significant variation in average insulation levels when looking at single-family home buildings differentiated by construction year (Kragh and Rose 2011). Furthermore, warm edge windows with double pane low-emissive glazing can have heat thermal transmittance rates approximately 50% lower than traditional double-pane wooden framed windows and are not represented equally across the construction years (Tommerup and Svendsen 2006). These variations make the decision about a representative single-family home building even more difficult. In a life cycle cost assessment of single-family homes from the Danish national building research institute (SBi), a Reference House was proposed as a representation of the Danish single family home building stock (Aggerholm 2013). This house is a single story building with a gross floor area of 162 m^2 and a net heated floor area of 149.6 m^2 built with insulation and glazing to meet the 2015 requirements for low-energy construction in newly built homes.

To create a Reference House for the purposes of our study, the floor plan and elevations of the SBI Reference House were redrawn in AutoCAD so that reliable measurements and variation based on insulation could be made. The redrawn Reference House (with 250mm wall insulation) has a foundation area of 170.8 m^2, a gross heated floor area of 151.2 m^2, a total window/door area: 35.8 m^2 (23.7% of HFA), and a total exterior wall area, which will vary slightly with wall insulation thickness, of 125.4 m^2 (Figure S1). These values are intended and here assumed to reflect the averages of single family homes in the Danish building stock as well as take into account the trend toward larger buildings in recent construction.

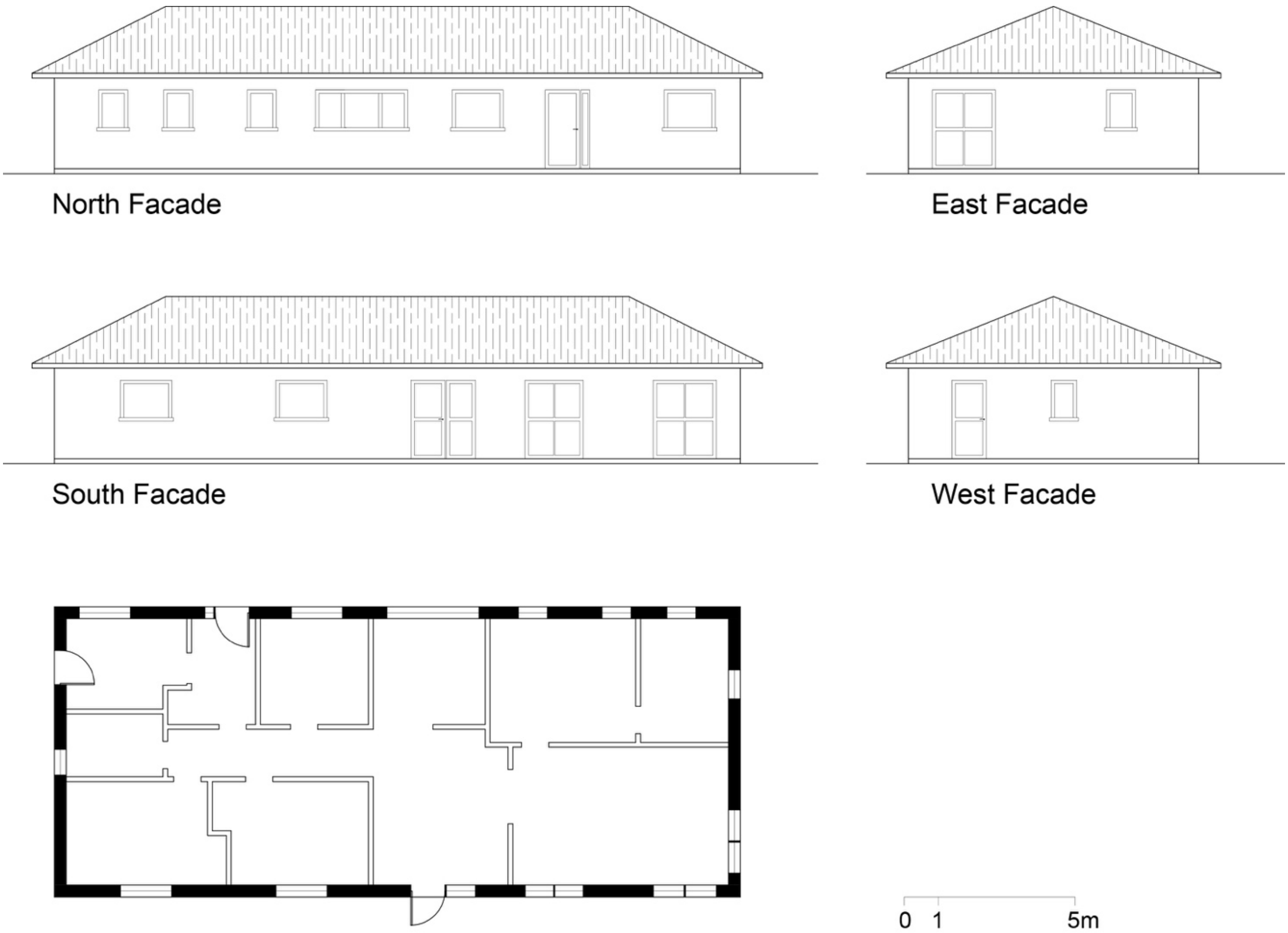


Figure S1: Floor plan and elevations of the Danish Reference House

The wall construction detail is assumed to have little effect on the relative assessment, as the insulating capability of the non-insulation layers of the wall section is relatively small and present across all insulation scenarios. For the purpose of our assessment, a lightweight concrete filled cavity wall with brick cladding was used due to its prevalence in the Danish market (Figure S2). The environmental impacts of the building structure based on the lowest level of insulation are ignored, as these are the same in all insulation scenarios. The primary additional building materials, brick cladding and roofing tiles, needed to allow for increased wall section depth due to increasing levels of insulation are accounted for in the assessment. However, due to the impracticality of quantification and relative insignificance other additional building materials such as the increase in use of mortar and roof sheathing are ignored.

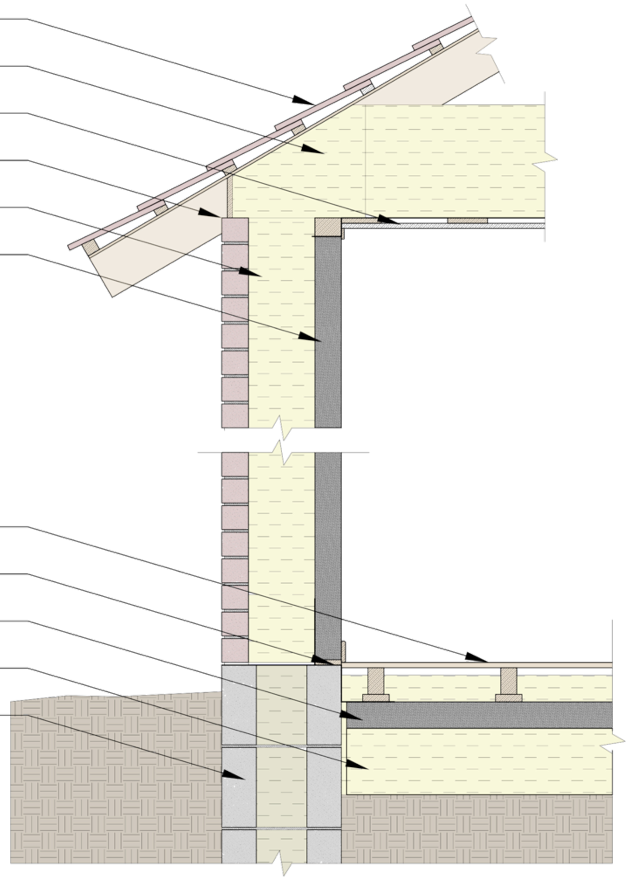


Figure S2: Schematic drawing of Brick cavity wall with lightweight concrete interior wall and floor slab

1.2 Building insulation scenarios

To observe the effect of increasing levels of insulation on environmental performance, ten (10) insulation scenarios were articulated as summarized in **Error! Reference source not found.** and Table S2. These scenarios, to be refereed henceforth as, the Danish Reference House and Energy Mix (DREM)1-10, representing a range of insulation levels meeting the energy loss requirements of the three classes for residential buildings in Danish Building Regulations 2010 (BR10), which is in effect until July of 2016 (DEV 2010). One of the primary changes to these regulations, when the Building Regulations 2015 comes into effect, is that the voluntary Low-Energy 2015 building class (which is achieved by the DREM3 and above) will become a mandatory minimum. Because of this, the scenarios focus on insulation levels that meet the Low-Energy 2015 classification as well as the voluntary Building Class 2020.

Table S1: Insulation thicknesses (mm) and total mass (ton) and associated building regulatory levels for the DREM scenarios

	Meets BR2010*		Meets Low Energy 2015*					Meets Building Class 2020*		
	DREM1	DREM2	DREM3	DREM4	DREM5	DREM6	DREM7	DREM8	DREM9	DREM10
Wall [mm]	100	150	200	250	300	350	400	450	500	550
Roof [mm]	200	275	350	425	500	575	650	725	800	875
Slab [mm]	200	250	300	350	400	450	500	550	600	650
Mass [ton]	3.24**	4.42**	5.61**	6.82**	8.05**	9.30**	10.57**	11.86**	13.17**	14.50**

*Based on energy loss calculations in BE10 with heat supplied by district heating

**Based on a density of 41 kg/m^3 (Deutsche Rockwool 2012)

Table S2: Insulation scenario u-values (W/(m^{2}K)) for the DREM scenarios.

	DREM1	DREM2	DREM3	DREM4	DREM5	DREM6	DREM7	DREM8	DREM9	DREM10
Wall [W/m^{2}K]	0.300	0.218	0.172	0.141	0.120	0.104	0.092	0.083	0.075	0.069
Roof [W/m^{2}K]	0.170	0.129	0.104	0.087	0.075	0.066	0.058	0.053	0.048	0.044
Slab [W/m^{2}K]	0.149	0.123	0.105	0.092	0.081	0.073	0.066	0.061	0.056	0.052

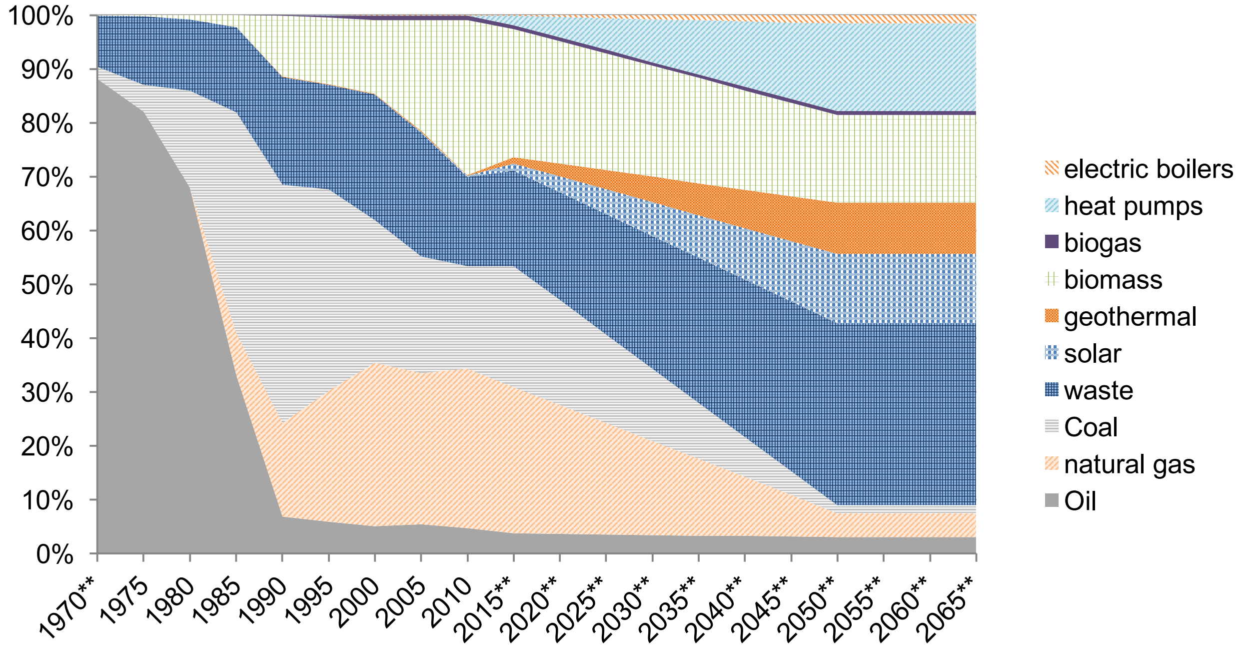
To allow for realistic levels of insulation as well as a linear increase in insulation volume throughout the DREM scenarios, the roof insulation was increased at a rate of 75mm per scenario step, while wall and slab insulation were increased at a rate of 50mm per scenario step. The roof and slab insulation were also both given a baseline at 200mm while the wall insulation was given a baseline of 100mm. This baseline level was set as the lowest practical level of insulation to meet 2010 Danish building regulations based on total envelope heat loss based energy loss calculations in BE10 with heat supplied by district heating (DEV 2010). These varying baselines and rates of increase in insulation further reflect practical factors for insulation design such as the physical limits in wall insulation thickness before wall depths begin to significantly reduce available light from windows, the availability of space for insulation in the roof cavity and slab, and the reduced effect of slab insulation due to the differences in heat loss to the surrounding soil matrix versus the losses to air on the other building surfaces.

1.3 District heating energy mix

The majority of Danish residential buildings are heated by district heating, and the proportion of residential units heated by district heating is rising (Dansk Fjernvarme 2015). In 2013, heating in Danish households was provided by: District heating 62.4%, natural gas boilers 15.5%, oil-fired boilers 11.9%, and other 10.2%, which is comprised of heat pumps, electric resistance, wood-fired boilers, solar, etc. (DEA 2015). The presence of oil fired and natural gas boilers is expected to diminish over the coming decades and are estimated to be completely removed from the energy supply by 2050 (DEA 2011). For the purposes of our study, only buildings supplied by district heating are represented, as they reflect the majority of households, will become (even) more prevalent over time, and the supply mix is more directly regulated by policy which allows for reliable and valid projection.

The composition of the Danish district heat supply has changed significantly since 1972, the earliest year reported in the Danish annual energy report (DEA 2015). Sources of heat production have changed from primarily oil with some coal and waste to a production where oil has been almost entirely replaced by natural gas and biomass (Energistyrelsen, 2015). The Danish District Heating Association has laid out future scenarios for development of the Danish district heating supply, and these scenarios have been quantified into a projected supply mix (Rasmussen 2012). The historic data were grouped to match the source categories in the future district-heating scenario and both were combined to create an energy mix applicable for assessing optimum insulation for construction years that spans from 1972-2015 (Figure S3).

For the calculation of a building lifetime heat supply, the annual energy mix values for 50 years following construction were averaged (Figure S4). Given the lack of a projection after 2050, the 2050 energy mix was assumed to be representative for all years between 2050 and 2065. These averages were then used as the proportions in developing a construction year dependent heat mix scenario, which was used in concert with insulation scenarios, to assess performance of the differing insulation scenarios along with the changing future energy mix.



**indicates a hindcast or forecast

Figure S3: Proportion of district heat production sources 1970-2050 present in the Danish energy supply

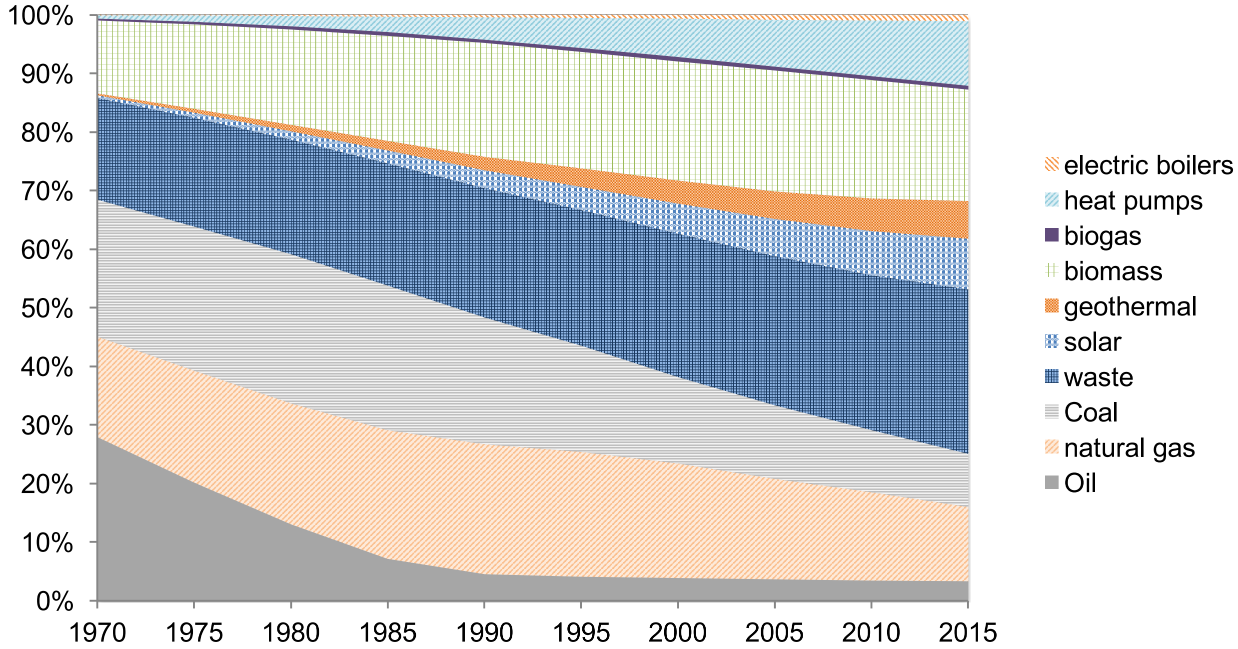


Figure S4: Proportion of district heat production sources present in the Danish energy supply for service life (50 year) building heat use by construction year

1.4 Building energy model

In calculating potential building heat losses across the varying insulation scenarios (Table S2 and Table S3), a building heat loss model is necessary. Because aligning the insulation scenarios with Danish regulations was a priority, BE10v7 a building heat loss modelling software developed by the Danish Building Research Institute was considered appropriate and chosen for the energy modeling (Aggerholm and Sørensen 2016). It allows for direct output of building energy use estimates with their associated relationship to Danish building regulations. It also allows for easy input of climate data from a number of predetermined locations as well as the use of METEONORM and ASHRAE climate projections, average, and historical data.

Values for building components, not including the insulation but related to heat loss, such as windows, foundation, ventilation, *etc*. were chosen to fit with a range of insulation scenarios that includes all assessed insulation scenarios. This selection was made following the logic that it is unlikely that a builder would over-optimize one system such as windows while installing a bare minimum of insulation in the walls, roof, and slab. In order to allow for comparability across scenarios, these parameters were set at fixed values across all insulation scenarios. Furthermore, without setting these other variables to a fixed value, and thus reducing the insulation scenarios to a single variable change (insulation level) comparison of the impact of the insulation across insulation scenarios would have been complicated if not precluded.

The window parameters were selected to approximate a very high performing double pane argon filled window with low-emissivity coating. This window type was approximated using a U-value of 1 W/m^{2}K and a solar transmittance factor of 0.6. The foundation parameters were selected to approximate a high performing filled cavity foundation block with a linear loss of 0.12 W/mK. The use of a mechanical heat recovery ventilation system was also assumed with a rate of function of 70% corresponding to natural summer ventilation, a heat recovery efficiency of 85%, a winter ventilation rate of 0.3 l/s per m^2 with 0.06 l/s per m^2 of infiltration, and a summer rate of 0.3 l/s per m^2 with a natural summer ventilation rate of 1.2 l/s per m^2. It was also assumed that the building had average occupancy and a standard water heater leaking some heat into the building as defined in the standard values for BE10v7 based on DS/EN ISO 12241, (Aggerholm and Sørensen 2011). Using these parameters as well as the default Danish climate data, a lifetime heat use could be established for each insulation scenario (Table S3).

1.5 Insulation and energy scenarios

The R-values (m^{2}K/W) used in calculating the wall, roof, and slab U-values were based on generic average material R-values (pls. refer to **Table S4**), and insulation scenario U-values (W/m^{2}K) were calculated as $\boldsymbol{U} = \frac{\mathbf{1}}{\sum(\boldsymbol{Component\ R{-}values})}$ (Martin 2016). The assembled building component U-values model values were then compared with industry calculated U-values revealing a variance of less than 1% (Rockwool 2015).

Table S3: Lifetime reference home heat requirement for DREM insulation scenarios

	Meets BR2010*		Meets Low Energy 2015*					Meets Building Class 2020*		
	DREM 1	DREM 2	DREM 3	DREM 4	DREM 5	DREM 6	DREM 7	DREM 8	DREM 9	DREM10
Lifetime building heat requirement (Mwh)	302.5	217.5	171.5	142	121.5	107	94.5	86	78.5	72
Insulation mass (tons)	3.24	4.42	5.61	6.82	8.05	9.30	10.57	11.86	13.17	14.50

*Based on energy loss calculations in BE10 with heat supplied by district heating

Table S4: Building component R-values based on generic values (Martin 2016)

Wall R-value ((m^2K)/W)		
Material	**Calculation type**	**Component R-value** (m^2K/W)
Mineral wool insulation	Per cm	0.250
Aerated concrete	Per cm	0.073
Brick	Per whole building element	0.007
Air Film	Per whole building element	0.037
Ceiling R-value ((m^2K)/W)		
Material	**Calculation type**	**Component R-value** (m^2K/W)
Mineral wool insulation	Per cm	0.250
Roof sheathing and shingles	Per whole building element	0.171
Air space	Per whole building element	0.440
Gypsum ceiling panel	Per whole building element	0.099
Air Film	Per whole building element	0.171
Slab R-value ((m^2K)/W)		
Material	**Calculation type**	**Component R-value** (m^2K/W)
Mineral wool insulation	Per cm	0.277
Aerated concrete	Per cm	0.073
Air space	Per whole building element	0.176
Flooring	Per whole building element	0.282

Table S5: Ecoinvent 3.2 processes used to model heat production

Production Category	Ecoinvent 3.2 attributional processes
Oil	heat, district or industrial, other than natural gas | heat and power co-generation, oil – DK
Natural gas	heat, district or industrial, natural gas | heat and power co-generation, natural gas, combined cycle power plant, 400MW electrical - DK
Coal	heat, district or industrial, other than natural gas | heat and power co-generation, hard coal – DK
Waste*	Heat, district, from waste
Solar	heat, central or small-scale, other than natural gas | operation, solar collector system, evacuated tube collector, one-family house, for combined system - CH
Geothermal	heat, borehole heat pump | heat production, borehole heat exchanger, brine-water heat pump 10kW – Europe without Switzerland
Biomass	heat, district or industrial, other than natural gas | heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 - DK
Biogas*	Heat, district, from biogas
Heat pumps	heat, air-water heat pump 10kW | heat production, air-water heat pump 10kW – Europe without Switzerland
Electric boilers	heat, district, from electric boiler* (electricity, high voltage | electricity, high voltage, production mix - DK)

*Indicates a custom process

Table S6: Ecoinvent 3.2 processes used to model insulation and related processes

Insulation and related materials	Ecoinvent 3.2 attributional (APOS) processes
Mineral Wool	rock wool, packed | rock wool production, packed – CH
Roof Tiles	roof tile | roof tile production – RER'
Facade Bricks	clay brick | clay brick production – RER
Transportation	transport, freight, lorry 16-32 metric ton, EURO5 | transport, freight, lorry 16-32 metric ton, EURO5

Section 2 Detailed Results

Table S7: ILCD 2011 Midpoint impact results for 1972 and 2015 with static and dynamic energy mix

	Dynamic - 1972										
Impact category	DREM1	DREM 2	DREM 3	DREM 4	DREM 5	DREM 6	DREM 7	DREM 8	DREM 9	DREM 10	Units
Acidification	7.93E+02	6.06E+02	5.13E+02	4.62E+02	4.33E+02	4.19E+02	4.10E+02	4.11E+02	4.15E+02	4.21E+02	Mole H+ eq.
Climate change	8.87E+04	6.75E+04	5.70E+04	5.10E+04	4.76E+04	4.59E+04	4.47E+04	4.47E+04	4.50E+04	4.56E+04	kg CO2 eq.
Freshwater ecotoxicity	4.72E+04	3.79E+04	3.39E+04	3.21E+04	3.17E+04	3.21E+04	3.28E+04	3.41E+04	3.55E+04	3.72E+04	CTUe
Freshwater eutrophication	1.72E+01	1.35E+01	1.18E+01	1.10E+01	1.06E+01	1.06E+01	1.06E+01	1.09E+01	1.12E+01	1.16E+01	kg P eq.
Human toxicity - carcinogenics	1.86E-03	1.50E-03	1.34E-03	1.28E-03	1.26E-03	1.28E-03	1.31E-03	1.36E-03	1.42E-03	1.49E-03	CTUh
Human toxicity - non-carcinogenics	7.03E-03	5.50E-03	4.79E-03	4.44E-03	4.27E-03	4.24E-03	4.25E-03	4.35E-03	4.47E-03	4.62E-03	CTUh
Ionizing radiation - ecosystems	1.76E-02	1.33E-02	1.12E-02	9.94E-03	9.21E-03	8.82E-03	8.54E-03	8.49E-03	8.50E-03	8.57E-03	CTUe
Ionizing radiaton - human health	2.89E+03	2.27E+03	1.98E+03	1.84E+03	1.77E+03	1.76E+03	1.77E+03	1.81E+03	1.87E+03	1.94E+03	kg U235 eq.
Land use	9.47E+04	7.00E+04	5.72E+04	4.93E+04	4.43E+04	4.10E+04	3.84E+04	3.71E+04	3.60E+04	3.53E+04	kg SOC
Marine eutrophication	7.10E+01	5.46E+01	4.66E+01	4.23E+01	3.99E+01	3.89E+01	3.83E+01	3.87E+01	3.93E+01	4.01E+01	kg N eq.
Ozone depletion	8.37E-03	6.26E-03	5.17E-03	4.53E-03	4.13E-03	3.89E-03	3.71E-03	3.63E-03	3.58E-03	3.56E-03	kg CFC-11 eq.
Particulate matter/Respiratory inorganics	5.31E+01	4.19E+01	3.69E+01	3.44E+01	3.35E+01	3.35E+01	3.38E+01	3.48E+01	3.60E+01	3.74E+01	kg PM2.5 eq.
Photochemical ozone formation	2.39E+02	1.88E+02	1.64E+02	1.52E+02	1.46E+02	1.45E+02	1.46E+02	1.50E+02	1.54E+02	1.59E+02	kg C2H4 eq.
Resource depletion - mineral, fossils and renewables	1.95E-03	2.50E-03	3.08E-03	3.70E-03	4.33E-03	4.97E-03	5.63E-03	6.30E-03	6.98E-03	7.67E-03	kg Sb eq.
Resource depletion - water	1.28E+01	1.00E+01	8.79E+00	8.16E+00	7.89E+00	7.86E+00	7.90E+00	8.11E+00	8.36E+00	8.66E+00	m3
Terrestrial eutrophication	8.13E+02	6.40E+02	5.62E+02	5.24E+02	5.08E+02	5.07E+02	5.11E+02	5.25E+02	5.43E+02	5.63E+02	Mole N eq.

	Static - 1972										
Impact category	DREM1	DREM 2	DREM 3	DREM 4	DREM 5	DREM 6	DREM 7	DREM 8	DREM 9	DREM 10	Units
Acidification	1.70E+03	1.25E+03	1.02E+03	8.75E+02	7.80E+02	7.18E+02	6.68E+02	6.40E+02	6.17E+02	6.01E+02	Mole H+ eq.
Climate change	1.07E+05	8.00E+04	6.62E+04	5.81E+04	5.30E+04	5.00E+04	4.77E+04	4.68E+04	4.62E+04	4.60E+04	kg CO2 eq.
Freshwater ecotoxicity	5.81E+04	4.51E+04	3.89E+04	3.57E+04	3.40E+04	3.35E+04	3.33E+04	3.39E+04	3.46E+04	3.56E+04	CTUe
Freshwater eutrophication	4.49E+00	4.19E+00	4.28E+00	4.54E+00	4.91E+00	5.34E+00	5.80E+00	6.32E+00	6.85E+00	7.40E+00	kg P eq.
Human toxicity - carcinogenics	8.71E-04	7.60E-04	7.35E-04	7.48E-04	7.82E-04	8.31E-04	8.85E-04	9.49E-04	1.02E-03	1.09E-03	CTUh
Human toxicity - non-carcinogenics	3.01E-03	2.54E-03	2.39E-03	2.37E-03	2.43E-03	2.54E-03	2.66E-03	2.83E-03	3.01E-03	3.19E-03	CTUh
Ionizing radiation - ecosystems	4.44E-02	3.25E-02	2.62E-02	2.23E-02	1.96E-02	1.79E-02	1.64E-02	1.56E-02	1.48E-02	1.43E-02	CTUe
Ionizing radiaton - human health	6.82E+03	5.06E+03	4.15E+03	3.60E+03	3.25E+03	3.03E+03	2.86E+03	2.77E+03	2.71E+03	2.67E+03	kg U235 eq.

Land use	2.37E+05	1.72E+05	1.37E+05	1.15E+05	1.00E+05	9.01E+04	8.14E+04	7.59E+04	7.11E+04	6.71E+04	kg SOC
Marine eutrophication	1.23E+02	9.16E+01	7.52E+01	6.54E+01	5.91E+01	5.52E+01	5.21E+01	5.06E+01	4.95E+01	4.88E+01	kg N eq.
Ozone depletion	1.79E-02	1.31E-02	1.05E-02	8.92E-03	7.85E-03	7.12E-03	6.52E-03	6.15E-03	5.84E-03	5.59E-03	kg CFC-11 eq.
Particulate matter/Respiratory inorganics	1.10E+02	8.23E+01	6.81E+01	5.97E+01	1.85E+01	5.13E+01	4.89E+01	4.79E+01	4.72E+01	4.70E+01	kg PM2.5 eq.
Photochemical ozone formation	4.46E+02	3.34E+02	2.77E+02	2.43E+02	2.21E+02	2.09E+02	1.99E+02	1.95E+02	1.93E+02	1.92E+02	kg C2H4 eq.
Resource depletion - mineral, fossils and renewables	1.75E-03	2.18E-03	2.65E-03	3.16E-03	3.68E-03	4.21E-03	4.76E-03	5.32E-03	5.89E-03	6.47E-03	kg Sb eq.
Resource depletion - water	1.69E+01	1.29E+01	1.09E+01	9.75E+00	9.11E+00	8.78E+00	8.56E+00	8.57E+00	8.63E+00	8.74E+00	m3
Terrestrial eutrophication	1.37E+03	1.03E+03	8.61E+02	7.62E+02	7.02E+02	6.69E+02	6.44E+02	6.37E+02	6.34E+02	6.36E+02	Mole N eq.

	Dynamic - 2015										
Impact category	DREM1	DREM 2	DREM 3	DREM 4	DREM 5	DREM 6	DREM 7	DREM 8	DREM 9	DREM 10	Units
Acidification	2.49E+02	2.09E+02	1.95E+02	1.92E+02	1.96E+02	2.04E+02	2.14E+02	2.26E+02	2.40E+02	2.55E+02	Mole H+ eq.
Climate change	3.95E+04	3.15E+04	2.80E+04	2.65E+04	2.60E+04	2.62E+04	2.67E+04	2.76E+04	2.87E+04	3.00E+04	kg CO2 eq.
Freshwater ecotoxicity	4.17E+04	3.32E+04	2.96E+04	2.79E+04	2.74E+04	2.76E+04	2.82E+04	2.92E+04	3.04E+04	3.17E+04	CTUe
Freshwater eutrophication	1.77E+01	1.37E+01	1.18E+01	1.08E+01	1.02E+01	1.00E+01	9.94E+00	1.01E+01	1.03E+01	1.05E+01	kg P eq.
Human toxicity - carcinogenics	2.00E-03	1.57E-03	1.37E-03	1.28E-03	1.23E-03	1.23E-03	1.24E-03	1.27E-03	1.31E-03	1.36E-03	CTUh
Human toxicity - non-carcinogenics	9.41E-03	7.14E-03	6.01E-03	5.37E-03	5.00E-03	4.80E-03	4.66E-03	4.65E-03	4.67E-03	4.72E-03	CTUh
Ionizing radiation - ecosystems	1.59E-02	1.20E-02	1.00E-02	8.86E-03	8.18E-03	7.79E-03	7.51E-03	7.44E-03	7.42E-03	7.46E-03	CTUe
Ionizing radiaton - human health	6.17E+03	4.60E+03	3.79E+03	3.30E+03	2.99E+03	2.80E+03	2.66E+03	2.59E+03	2.54E+03	2.52E+03	kg U235 eq.
Land use	4.12E+03	4.57E+03	5.25E+03	6.04E+03	6.90E+03	7.80E+03	8.73E+03	9.69E+03	1.07E+04	1.17E+04	kg SOC
Marine eutrophication	3.38E+01	2.72E+01	2.45E+01	2.34E+01	2.31E+01	2.35E+01	2.41E+01	2.51E+01	2.63E+01	2.75E+01	kg N eq.
Ozone depletion	1.73E-02	1.26E-02	1.02E-02	8.63E-03	7.60E-03	6.90E-03	6.32E-03	5.97E-03	5.68E-03	5.44E-03	kg CFC-11 eq.
Particulate matter/Respiratory inorganics	2.06E+01	1.80E+01	1.74E+01	1.77E+01	1.85E+01	1.96E+01	2.09E+01	2.24E+01	2.40E+01	2.57E+01	kg PM2.5 eq.
Photochemical ozone formation	1.01E+02	8.58E+01	8.09E+01	8.06E+01	8.28E+01	8.68E+01	9.14E+01	9.73E+01	1.04E+02	1.10E+02	kg C2H4 eq.
Resource depletion - mineral, fossils and renewables	2.99E-03	3.07E-03	3.36E-03	3.74E-03	4.18E-03	4.65E-03	5.15E-03	5.67E-03	6.21E-03	6.77E-03	kg Sb eq.
Resource depletion - water	1.39E+01	1.07E+01	9.15E+00	8.32E+00	7.88E+00	7.70E+00	7.61E+00	7.70E+00	7.83E+00	8.02E+00	m3
Terrestrial eutrophication	4.02E+02	3.36E+02	3.13E+02	3.08E+02	3.14E+02	3.27E+02	3.42E+02	3.62E+02	3.83E+02	4.06E+02	Mole N eq.

	Static - 2015										
Impact category	DREM1	DREM 2	DREM 3	DREM 4	DREM 5	DREM 6	DREM 7	DREM 8	DREM 9	DREM 10	Units
Acidification	2.53E+02	2.12E+02	1.97E+02	1.94E+02	1.98E+02	2.06E+02	2.15E+02	2.28E+02	2.41E+02	2.56E+02	Mole H+ eq.
Climate change	4.99E+04	3.90E+04	3.39E+04	3.13E+04	3.01E+04	2.98E+04	2.99E+04	3.06E+04	3.14E+04	3.25E+04	kg CO2 eq.
Freshwater ecotoxicity	3.06E+04	2.53E+04	2.33E+04	2.28E+04	2.30E+04	2.38E+04	2.47E+04	2.61E+04	2.75E+04	2.91E+04	CTUe
Freshwater eutrophication	1.42E+01	1.12E+01	9.80E+00	9.11E+00	8.82E+00	8.78E+00	8.84E+00	9.08E+00	9.37E+00	9.71E+00	kg P eq.

Human toxicity - carcinogenics	1.52E-03	1.23E-03	1.10E-03	1.05E-03	1.04E-03	1.06E-03	1.09E-03	1.13E-03	1.19E-03	1.24E-03	CTUh
Human toxicity - non-carcinogenics	8.22E-03	6.29E-03	5.34E-03	4.81E-03	4.52E-03	4.38E-03	4.29E-03	4.31E-03	4.36E-03	4.43E-03	CTUh
Ionizing radiation - ecosystems	5.61E-03	4.59E-03	4.18E-03	4.04E-03	4.05E-03	4.16E-03	4.31E-03	4.52E-03	4.76E-03	5.02E-03	CTUe
Ionizing radiaton - human health	1.62E+03	1.32E+03	1.20E+03	1.16E+03	1.16E+03	1.19E+03	1.23E+03	1.29E+03	1.36E+03	1.43E+03	kg U235 eq.
Land use	1.58E+04	1.29E+04	1.18E+04	1.15E+04	1.16E+04	1.19E+04	1.24E+04	1.30E+04	1.37E+04	1.45E+04	kg SOC
Marine eutrophication	3.43E+01	2.76E+01	2.48E+01	2.36E+01	2.33E+01	2.37E+01	2.43E+01	2.53E+01	2.64E+01	2.77E+01	kg N eq.
Ozone depletion	5.76E-03	4.34E-03	3.63E-03	3.21E-03	2.96E-03	2.82E-03	2.72E-03	2.69E-03	2.68E-03	2.69E-03	kg CFC-11 eq.
Particulate matter/Respiratory inorganics	2.01E+01	1.76E+01	1.71E+01	1.74E+01	1.83E+01	1.94E+01	2.07E+01	2.23E+01	2.39E+01	2.56E+01	kg PM2.5 eq.
Photochemical ozone formation	1.06E+02	8.91E+01	8.35E+01	8.28E+01	8.47E+01	8.85E+01	9.29E+01	9.86E+01	1.05E+02	1.11E+02	kg C2H4 eq.
Resource depletion - mineral, fossils and renewables	1.79E-03	2.21E-03	2.68E-03	3.18E-03	3.70E-03	4.23E-03	4.78E-03	5.34E-03	5.90E-03	6.48E-03	kg Sb eq.
Resource depletion - water	9.89E+00	7.83E+00	6.90E+00	6.46E+00	6.29E+00	6.30E+00	6.38E+00	6.57E+00	6.81E+00	7.08E+00	m3
Terrestrial eutrophication	4.30E+02	3.56E+02	3.29E+02	3.21E+02	3.25E+02	3.36E+02	3.50E+02	3.69E+02	3.90E+02	4.13E+02	Mole N eq.

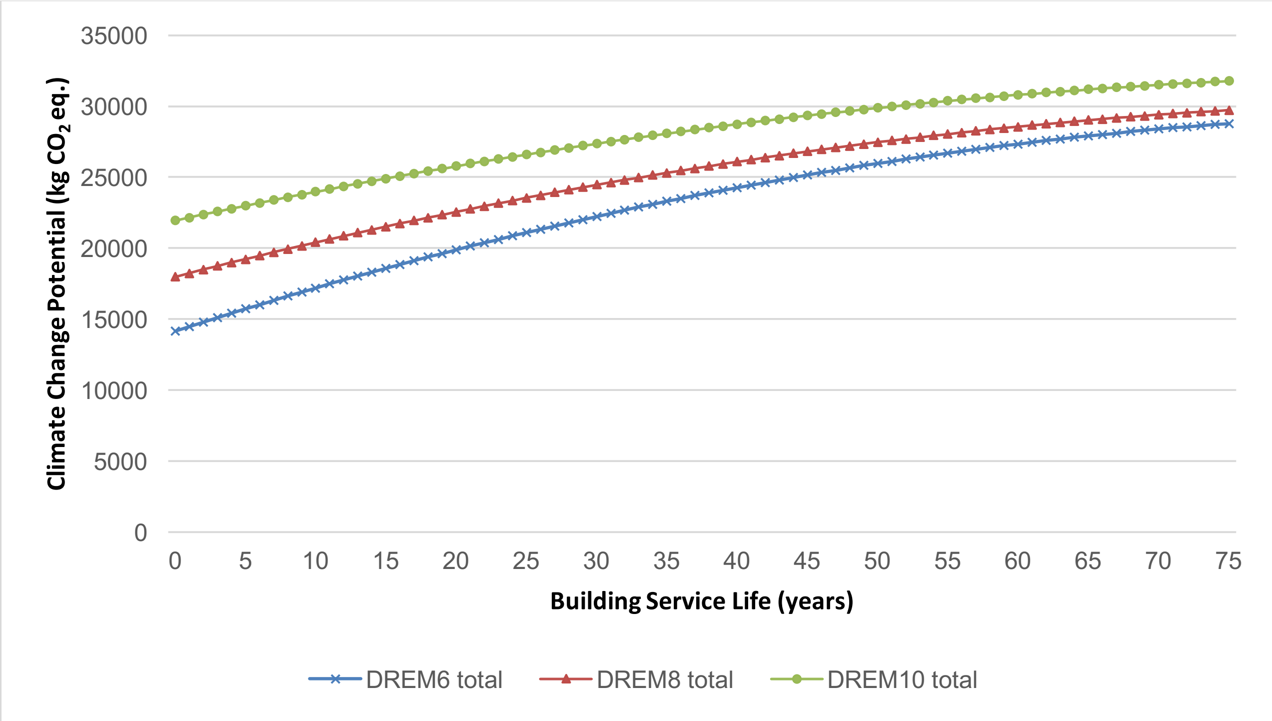


Figure S5: Marginal contribution to climate change (kg CO_2 eq.) of heating and insulation and related additional construction materials for DREM 6, 8, and 10 with 2015 construction year, dynamic energy scenario, and linear projection of energy mix contribution to climate change impacts for 2050-2090

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